Interpolation, PSTM, AVO, and a Thin Gas Charged Viking Shoreface in West Central Alberta*

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Abstract

Exploration and development of the Viking in West Central Alberta is challenging because this prolific zone is deep, structured, and very thin relative to tuning thickness. It represents an attractive economic prize, but even on the extensive 3D coverage that exists in the area, reservoir quality indicators such as porosity-thickness (Phi-H) are difficult to accurately predict. We attempted to exploit the AVO response of the gas charged zone on migrated gathers to obtain a more accurate estimate of Phi-H. A coarse 3D geometry led to the need to use a 5D interpolation prior to migration to minimize the migration artifacts that arise due to the insufficient sampling of the seismic wavefield. This interpolation migration flow was the most effective flow relative to other methods tried on this data, and represents an important new paradigm for land AVO analysis. This assertion is validated by 29 well ties and the resultant maps which are consistent with the structural erosional model of the Viking.

Introduction: The Viking Formation, and the Seismic Challenge it Represents

Viking Formation reservoirs in West Central Alberta represent attractive exploration targets. Reservoirs are comprised of shoreface sandstone assemblages that often retain 12-14 percent porosity over 0 to 7 meters thickness, and occur at depths greater than 2,800m. The sandstones have low permeabilities (< 1 mD) but are commonly overpressured and gas bearing with typical recoverable resource of eight Bcf and 80,000 bbls condensate per section. The structural setting for the area includes both extensional and compressional tectonic elements.

Figure 1 is a schematic cross section of two wells within the 3D survey. These wells were selected for the modeling work as they had full wireline log suites including shear and compressional sonic and core data. The section is hung on the Base Fish Scales (BFS) and shows two basin wide transgressive events labeled VE3 and VE4 (after Boreen and Walker, 1991). The preserved porosity in Well A is associated with the upper shoreface deposits below the VE3 surface.

In Well B, the VE3 surface is underlain by tight lower shoreface and basinal deposits with no reservoir quality. Tectonism during Viking time may have caused reactivation of basement-rooted faults, which created an irregular sea floor topography that was differentially eroded during basin wide transgressive events resulting in the complex aerial distribution of preserved porosity. In general, porous and permeable progradational shoreface deposits are preserved in structural lows.

Despite the coverage of 3D seismic, accurate reservoir prediction is very challenging. The productive reservoir, which may be entirely or partially eroded, is never greater than 1/15 of a wavelength in thickness. These variables contribute to a poor correlation between seismic amplitude and measures of porosity thickness. Recalling Figure 1, the Viking can be described as a more competent material sitting under a less competent half-space (the BFS zone). Thus, the Viking is a peak on a zero phase-stacked section. When porous and gas charged, a well resolved Viking zone may have a Type IIa AVO response, where the weak peak goes towards smaller amplitudes with increasing offset. Log data from Well A and B illustrate this response with the good quality reservoir in Well A versus the absent reservoir in Well B.

This response suggests that an advantage may lie with the utilization of this contrasting AVO effect. The structural setting demanded the use of PSTM gathers for the analysis. Unfortunately, the 3D coverage in the area has coarse source and receiver line geometries, which give rise to gross irregularities in the offset and azimuthal distribution of the data. Upon PSTM, these irregularities cause distortions, which adversely affect the AVO analysis.

Theory

Fractional elastic parameters such as the compressional (R_p) and shear reflectivity (R_s) may be estimated from the prestack seismic data by AVO Inversion such as the two-term Gidlow et al. (1992) equation $R(\theta) = R_p \sec^2\theta - 8R_s\gamma^2\sin^2\theta$ where θ is the average angle of incidence and γ is the average S-wave / P-wave velocity ratio. There exists a wide variety of AVO attributes that could have been used for mapping and validation in this paper. We chose a very simple parameter, the damped R_p to R_s ratio. The gas charged porous Viking reservoir should illustrate a drop in the R_p to R_s ratio relative to the tighter reservoir. This is consistent with other gas charged sandstones. Unfortunately, all of these parameters are notoriously difficult to estimate with the fidelity and resolution to be useful on many stratigraphic prospects. Yi, Downton, and Xu (2007) describe the crucial challenges involved in successfully estimating the elastic parameters. Those challenges include the need to obtain migrated gathers that have sufficient resolution and high S/N ratios. In this example, the structural deformation appears to be significant enough to require that AVO be performed on PSTM gathers. The nominal source and receiver line spacing of this 3D survey is 600m, and the data is noisy and bandlimited to about 55Hz. This acquisition geometry was not sampled sufficiently fine enough so that the wavefield would constructively and destructively interfere to image all the reflectors with a good S/N ratio.

To address this issue, Minimum Weighted Norm Interpolation (MWNI) (Liu and Sacchi, 2004; Trad, 2007) was employed to regularize the data prior to migration. The 5D interpolation is performed by solving a large inverse problem. In this case, the desired model is a super-sampled seismic dataset, the data is the original seismic dataset, and the linear model is the sampling operator. The resultant super-sampled seismic data contains data for every possible in-line, cross-line, offset, and azimuth combination. In practice, this creates so much data that it becomes impossible to deal with, so the algorithm only outputs a representative subset of this. In this case, we output twice as many shot and receiver lines as the original geometry, thus preserving the original geometry and data as a subset of the new volume. As the original data are preserved, it is easy to verify that the original AVO trend is preserved. Further, the minimum norm constraint applied in the spatial frequency domain tends to ensure that the amplitude changes slowly in all four spatial dimensions including offset and azimuth while honoring the original data. Figure 3 (a, b, c, d) shows a comparison of the original data at well locations A and B versus the interpolated data at the same locations. The AVO trend of the data has been preserved and is similar to the models shown in Figure 2. Similarly, Figure 3 (e, f, g, h) compares the prestack migrated (uninterpolated) data to the PSTM gathers after interpolation. For all the cases, the interpolated results have a superior S/N ratio than the noninterpolated gathers. This is partly due to the higher fold and, in the case of the interpolated PSTM gathers, better sampling of the wavefield prior to the migration resulting in less migration noise.

A Superlative Test Case: 3D Seismic with Significant Well Control

The 3D that we used for this test had some 29 Viking penetrations. Since the primary geologic goal was to predict Phi-H in any new prospective well, we loaded the Phi-H value as a top into each well on the 3D. We then extracted our Rp/Rs ratio attribute at each well point and plotted the attribute versus Phi-H. To quantify any improvements that our new method might yield, we created several versions of the data. Each version was processed identically to the others- except for the noted change (Table 1). By comparing results of our extracted AVO attribute (Rp/Rs) at the well control for each of the versions, we hope to be able to comment on the usefulness of our new paradigm. The correlation coefficient (CC) of this regression was used as the primary method of validation, and is denoted as CC in Table 1. Note that the interpolated PSTM result was the best. The PSTM versions were generally better than those not imaged. Interestingly, super-binning did not uniformly yield a better CC. Perhaps the trade off of footprint noise suppression versus structural and stratigraphic smearing compromised this technique.

Figure 4 compares a portion of the interpolated PSTM attribute map to the 5x5 superbinned CDP method, the 1x1 PSTM method, and the 5x5 PSTM method. Low Rp/Rs ratio values are in green to red, and are indicative of the better Viking reservoir. Although the CC values are an objective measure of the veracity of the AVO attribute, they can be hypersensitive to outliers. This is why a comparison of the quality of the map results and even the gathers are of significant additional value. For example, even though the 5x5 CDP method has a similar CC to the 5x5 PSTM method, it is clear from the map comparison that the 5x5 PSTM result is superior. In fact, the map comparison reveals that the CDP method is grossly inferior to all the PSTM (migrated) results. Wells A and B are also noted, and are discriminated quite well in all maps. The low Rp/Rs ratio trend has a spatially sharp, structurally influenced shape. This spatial sensitivity may be the strongest influence on the disappointing results of superbinning in this example. The interpolation method is designed to preserve the spatial fidelity of the data, and it appears to have done so. The same cannot be said about superbinning. Stability enhancement is better achieved prior to migration. In the regression and on the maps, it is clear that the new interpolated PSTM method yielded the best results. The dataset was also used to successfully predict the results of two new wells denoted with rig symbols on the maps.

Conclusions

The well control on our 3D allowed us to validate our method from a variety of means, including a quantitative measure of the relationship between Phi-H and an AVO attribute. Of the many variations of the seismic data that we compared, the interpolated PSTM gathers without superbinning was unequivocally the best. Interestingly, the variations that had PSTM were consistently superior to those that were not migrated. Despite our original opinion that imaging would be important, we were nevertheless surprised by how important it was on this data. Interpolation was also shown to be a better method of stabilization than simply superbinning the PSTM gathers. In fact, despite giving the map views a cleaner appearance, the net effect of superbinning did not consistently help our cross correlations- a result that surprised us. Comparisons of gather quality are consistent with the quantitative measures, and support the interpolation PSTM flow that we advocate.

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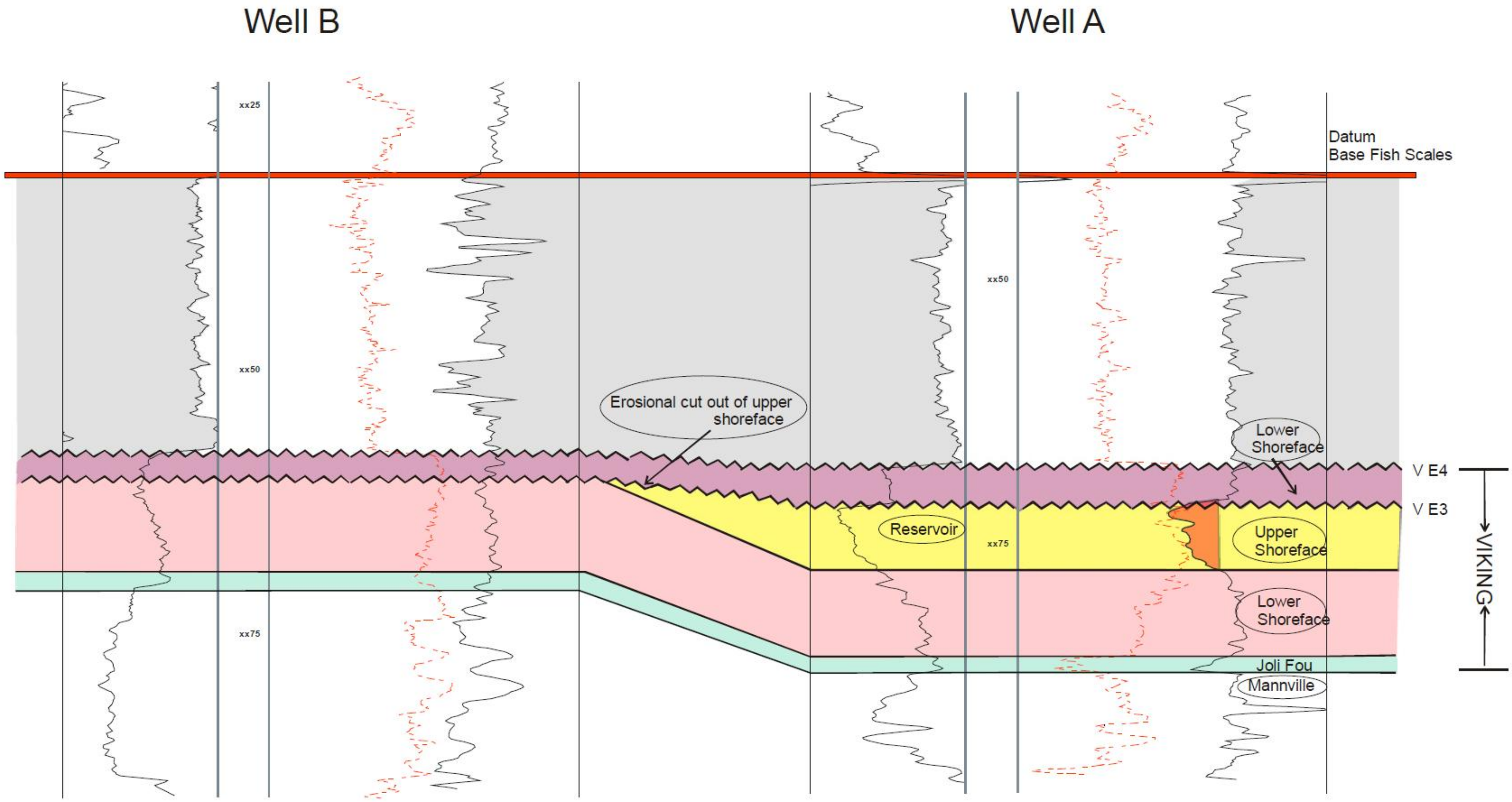


Figure 1. Stratigraphic cross section of two key wells within the 3D volume. Logs displays include gamma ray, density and neutron porosity curves. Well A (good reservoir) associated with preserved upper to middle shoreface deposits shows a 5 m thick section of sandstone reservoir with greater than 6% density porosity.

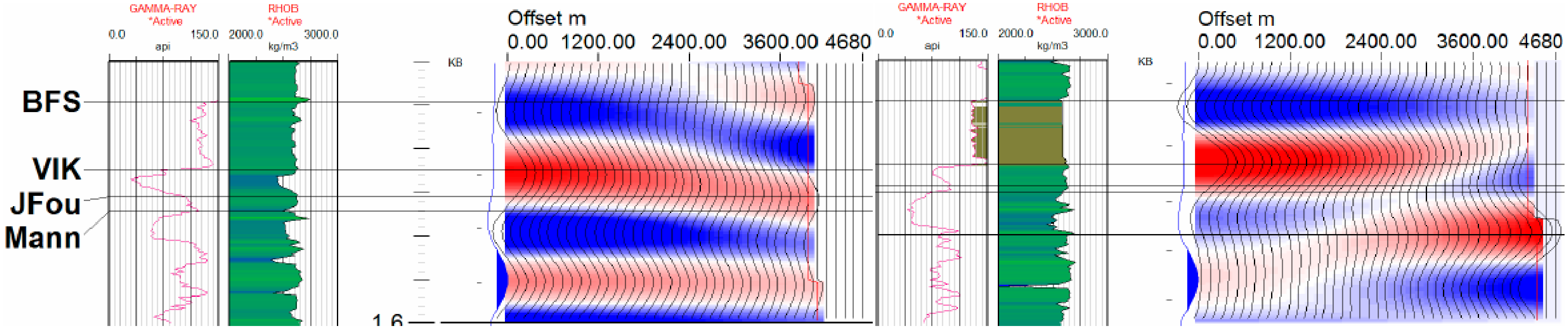


Figure 2. 0 to 35 degree AVO models created for Well A (good reservoir) and Well B (absent reservoir), respectively.

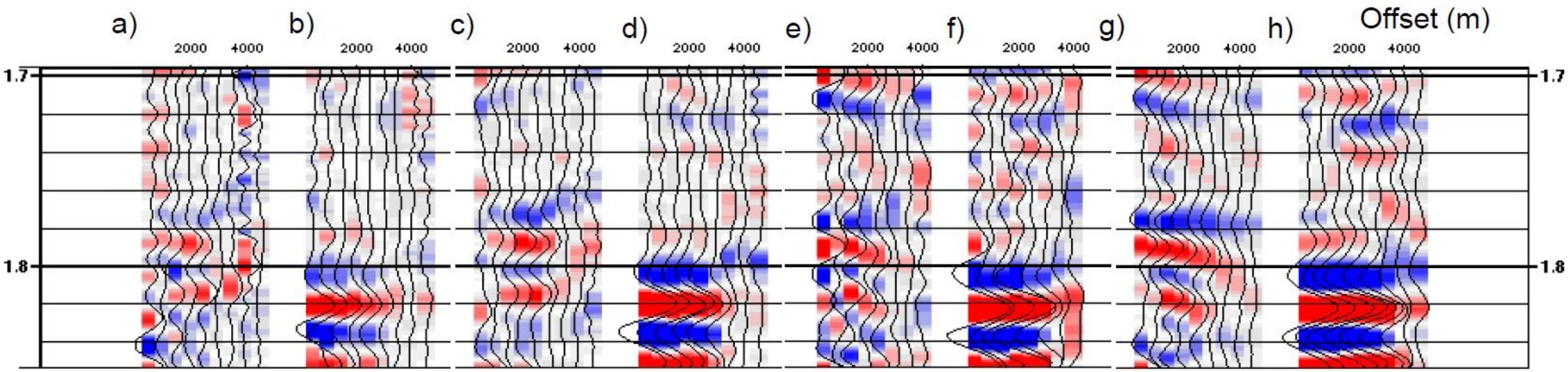


Figure 3. Ostrander gather at well A (a) & B (b), interpolated Ostrander gather at well A (c) and B (d), PSTM Ostrander gather at well A (e) and B (f), interpolated PSTM Ostrander gather at well A (g) and B (h). The Viking is at 1790 ms at well A and 1821 ms at well B.

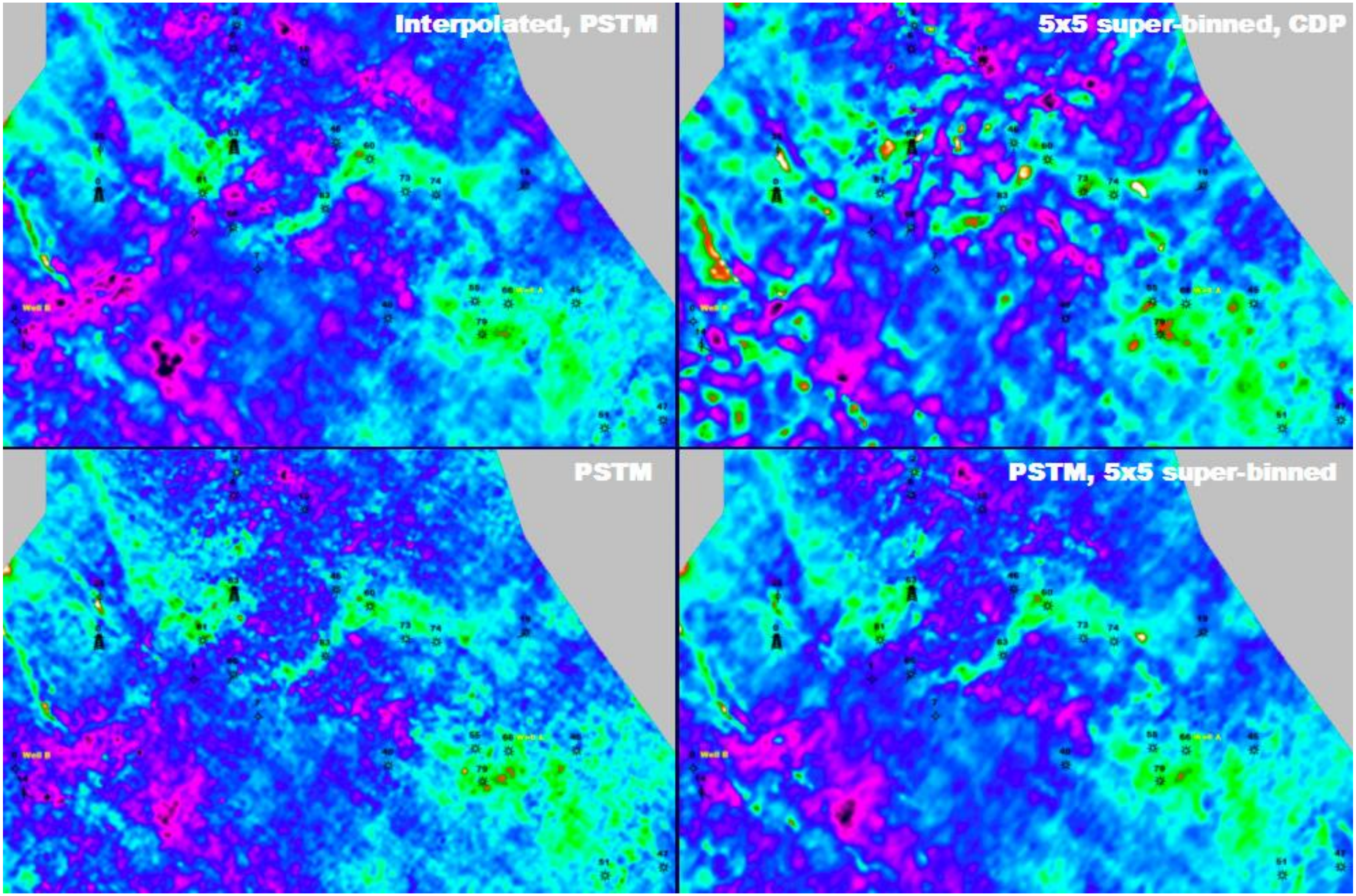
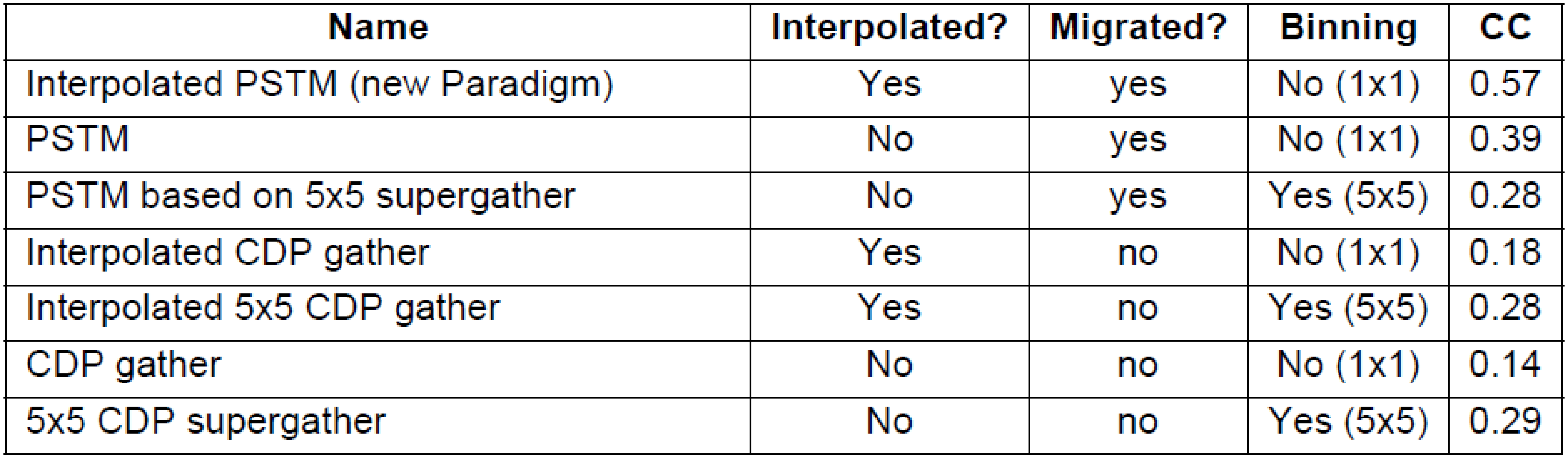


Figure 4. RpRs Ratio attributes. Top left -interpolated PSTM, top right – 5x5 CDP, bottom left – 1x1 PSTM, bottom right – 5x5 PSTM.



Name	Interpolated?	Migrated?	Binning	CC
Interpolated PSTM (new Paradigm)	Yes	yes	No (1x1)	0.57
PSTM	No	yes	No (1x1)	0.39
PSTM based on 5x5 supergather	No	yes	Yes (5x5)	0.28
Interpolated CDP gather	Yes	no	No (1x1)	0.18
Interpolated 5x5 CDP gather	Yes	no	Yes (5x5)	0.28
CDP gather	No	no	No (1x1)	0.14
5x5 CDP supergather	No	no	Yes (5x5)	0.29

Table 1. The versions of the data that the AVO attribute was extracted from and regressed with Phi-H. CC is the correlation coefficient of that regression.